

# **EDGEWOOD**

## **CHEMICAL BIOLOGICAL CENTER**

**U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND**

**ECBC-TR-412**

**DOMESTIC PREPAREDNESS PROGRAM:  
PROTECTION FACTOR TESTING OF THE SE-SHIELD SUIT  
WITH THE SE400 POWERED AIR PURIFYING RESPIRATOR (PAPR)**

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## Executive Summary

As part of the Domestic Preparedness Program, one Occupational Safety and Health Level B suit design was tested to assess its capability to protect in a chemical agent or biological agent environment. The suit design was tested for its protection factor (PF) in an aerosol environment (aerosolized corn oil, which may be representative of a chemical or biological agent, was used). Protection factor is defined as the ratio between the challenge concentration outside the suit and the measured concentration inside the suit. The tests are described, and the overall protection factors are presented.

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## PREFACE

This work described in this report was authorized under Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. The work was started and completed in December 2002.

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**DOMESTIC PREPAREDNESS PROGRAM:  
PROTECTION FACTOR TESTING OF THE SE-SHIELD SUIT  
WITH THE SE400 POWERED AIR PURIFYING RESPIRATOR (PAPR)**

**1. INTRODUCTION**

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance federal, state and local emergency and hazardous material (HAZMAT) response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, emergency and HAZMAT personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents or biological agents.

**2. OBJECTIVE**

This study evaluated the performance of the SE-Shield suit [Safety Equipment America (SEA) Inc., Branford, CT, <<http://www.sea.com.au/>>] in a corn oil challenge aerosol. The SE-SHIELD Level B suit is a chemically impermeable suit specially made for use with the SE400 Powered Air Purifying Respirator (PAPR). When used, the SE400 PAPR is equipped with a valve providing maximum 30 liter of air per minute into the suit to maintain positive pressure in the suit and compensate for possible suit leakage. Corn oil was used to simulate biological or chemical particulates from 0.4 to 0.6  $\mu\text{m}$  in diameter (typical military standard for the possible threat). This information is intended to evaluate the suit for its possible applications in the federal, state, and local emergency and HAZMAT areas. This is especially important if these personnel choose to include military chemical agent protection as a criterion for purchase.

**3. TESTING**

**3.1 Test Facilities and Equipment.**

Testing occurred at the Protection Factor Test Facility, an ISO 17025 compliant facility, in Building E5604, at Aberdeen Proving Ground – Edgewood Area, Edgewood, MD 21010, on Saturday, December 7, 2002. A challenge aerosol concentration of 20 – 40  $\text{mg}/\text{m}^3$ , polydispersed corn oil aerosol having a mass median aerodynamic diameter (MMAD) of 0.4 to 0.6  $\mu\text{m}$  (the Army Standard) was generated in a 10-ft  $\times$  20-ft  $\times$  32-ft test chamber. The test chamber challenge aerosol was generated by atomizing liquid corn oil at room temperature using a Laskin nozzle. The Laskin nozzle produced a coarse aerosol cloud, which was directed into an impaction plate to remove the larger particles and yield an aerosol in the desired size range. The concentrated aerosol from the generator was diluted with filtered ambient air to control the challenge aerosol concentration in the exposure chamber.

A 6-decade, 45° off-axis light-scattering laser photometer, sampling at a flow rate of 1 – 2 L/min, was used to quantify concentration of the challenge and the in-suit corn oil aerosols. For a given particle size, the quantity of scattered light is proportional to the aerosol concentration. The photometer converted the quantity of scattered light to a voltage, which was then digitized and recorded by a microcomputer.

### 3.2 Preparation of Test Items.

A total of eight SE-SHIELD suits were available for testing and all were prepared for the test. All suits were tested in the as-received condition so effects of aging, laundering, and temperature extremes is out of the scope of this test. The suits were probed in both the left neck region and the upper left arm region. Both sample lines were then connected by a 'Y' connection, which then was attached to a photometer once the volunteer was inside the chamber (Figure 1).

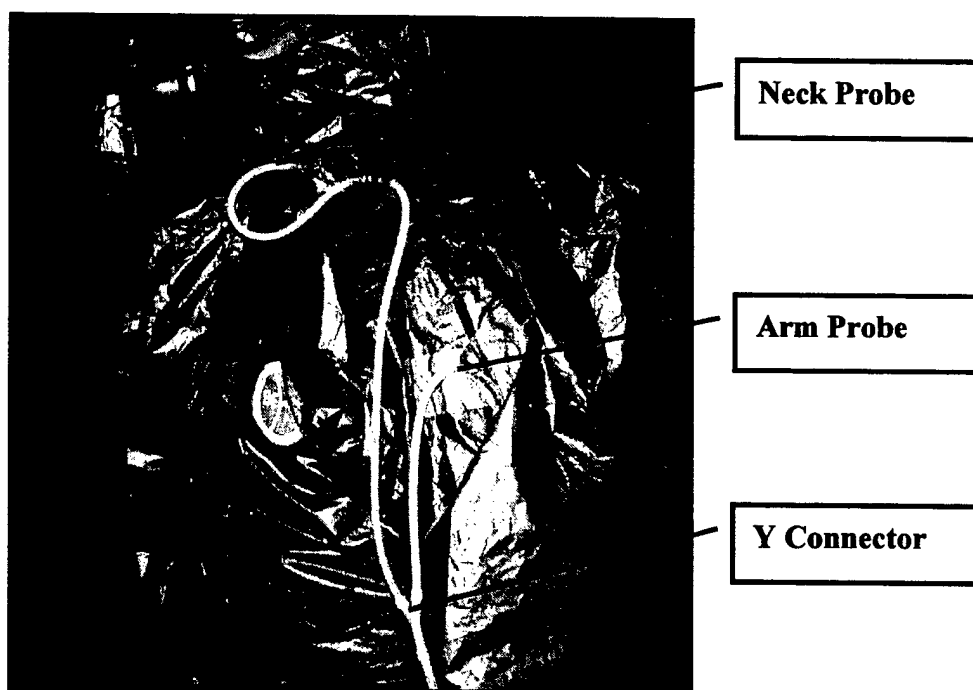


Figure 1. Probing Assembly

An SE400 PAPR was used in conjunction with the suit (Figure 2). The hoses on the PAPRs were replaced with new hoses, which contain a valve to dump a portion of air into the suit with the rest going into the facepiece. Also, the day prior to testing, all batteries for the PAPRs were discharged and then completely recharged so as to have a full charge for the test day. The SEA facepieces were a one-size-fits-all and no modifications were made to them for the test.

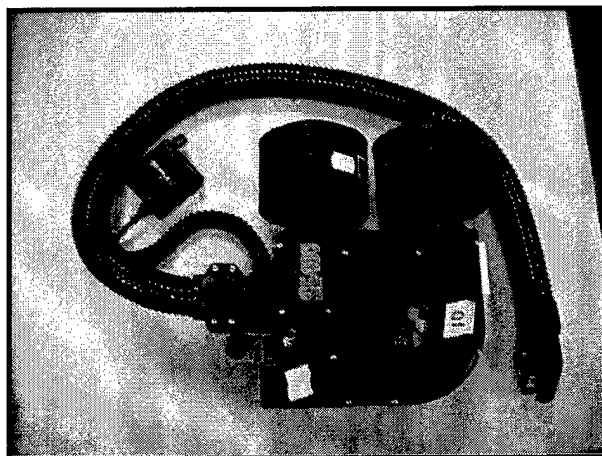


Figure 2. SE400 PAPR

### 3.3 Test Procedure.

On test day, 30 military volunteers entered the facility and from each some anthropometric data were taken, including face length and width, height, waist, inseam and chest. Of the 30 volunteers, 16 were chosen to be in the test. These volunteers best fit the suit and the full facepiece due to the manufacturers size specifications. Their measurements can be found in Appendix A. ECBC personnel then oriented the volunteers by explaining the test, and each volunteer was asked to sign an informed consent agreement.

The first eight volunteers were then instructed to prepare for the test. They changed out of their clothes and into coveralls, removing their boots as well. ECBC and SEA personnel dressed each subject into the suit and PAPR. The subjects wore a pair of boots outside of the suit, but no outer gloves were worn. The boots were worn to prevent the tearing of the suit while walking. Donning procedures for the suit included duct taping the seam in the front and along side of the head. Once all suits were correctly donned, the PAPRs were turned on and each was checked with a flow meter to ensure it was producing the correct amount of airflow.

The ECBC personnel then led the eight volunteers into the chamber and attached their sample tubes to the photometer, the latter was located outside of the chamber in the control room. Personnel from within the control room communicated to the volunteers to begin the test, consisting of the following exercises:

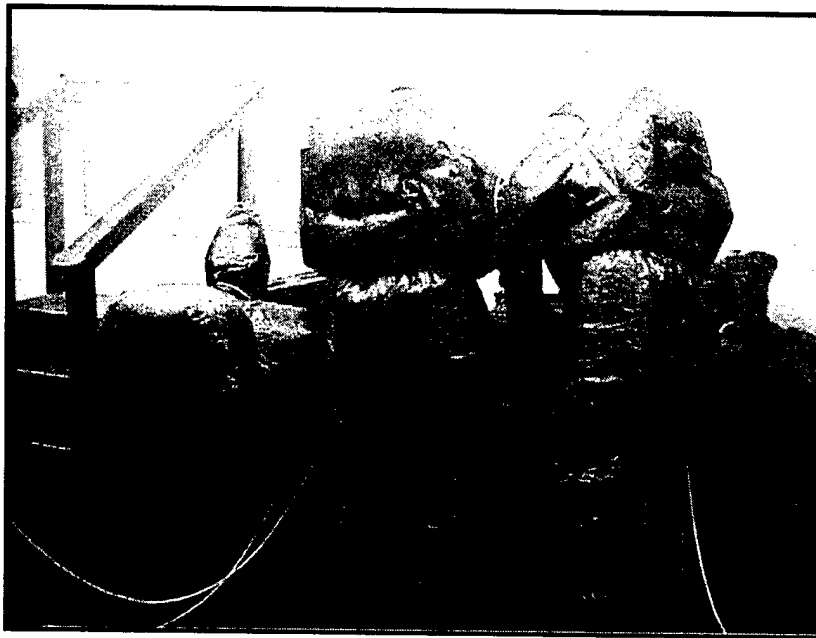
#### Part A (1 min each)

1. Normal Breathing
2. Bend Forward and Touch Toes
3. Jog in Place
4. Raise Arms Above Head and Look Upward
5. Bend Knees and Squat
6. Crawl on Hands and Knees
7. Stand, Fold Arms in Front of Chest and Twist Torso
8. Normal Breathing

**Part B (4 min each)**

1. Climb Step Ladder
2. Move Boxes from Floor to Table
3. Rest
4. Roll Walls and Ceiling
5. Bag Clothes
6. Rest
7. Loosen Bolts
8. Move Boxes from Floor to Table

The ECBC personnel in the control room communicated each exercise to the volunteers. Once the volunteers completed one complete trial (parts A and B), they exited the chamber and took a few minutes rest. They then reentered the chamber for a second trial. The trials (1A, 1B, 2A or 2B) and exercises (1 – 8) correspond to trial numbers and exercise numbers in the data listed in Appendix B. View Figures 3 and 4 for images of the volunteers performing the exercises.



**Figure 3. Volunteers Performing 'Loosen Bolts' Exercise**

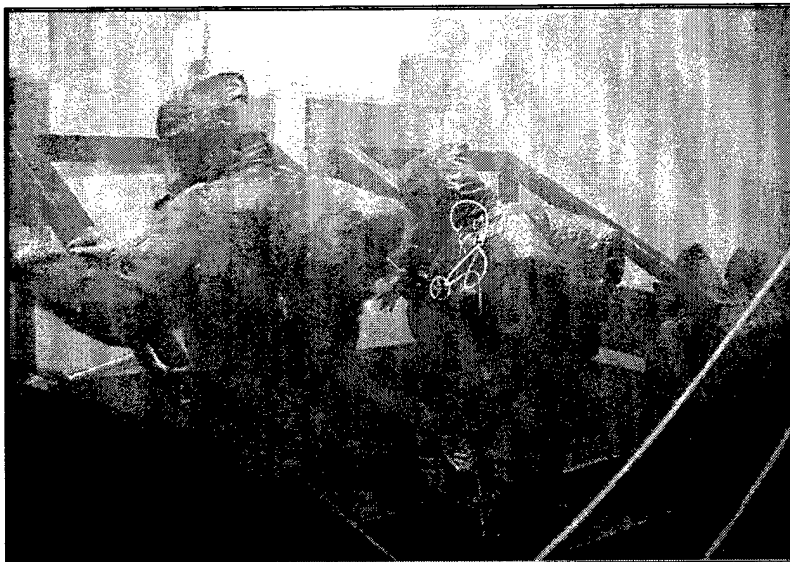


Figure 4. Volunteers Performing 'Climb Step Ladder' Exercise

Once the first group of eight volunteers completed two trials the second group prepared to enter the chamber. The second group performed the same procedures as the first group. With 16 volunteers each doing two trials, there was a possibility of 32 results for each exercise.

#### 4. DATA ANALYSIS

Suit performance was quantified in terms of a protection factor (PF). The PF was calculated by determining the ratio of the challenge aerosol concentration to the in-suit aerosol concentration as quantified by integrating the peak voltage output from the photometer over a time interval. A PF was calculated for each individual exercise ( $PF_i$ ):

$$PF_i = \frac{\text{Challenge Concentration}}{\text{In-Suit Concentration}}$$

The  $PF_i$ 's for a trial were then used to calculate an overall PF for a volunteer ( $PF_o$ ) as follows:

$$PF_o = n \left( \sum_{i=1}^n \frac{1}{PF_i} \right)^{-1}$$

where  $n$  is the number of exercises. The  $PF_o$  is affected most by the smallest  $PF_i$ . Under the conditions of this test and the sensitivity of the photometer, the maximum PF that can be reported is 100,000. In Appendix B, the  $PF_i$  is listed under each exercise and the  $PF_o$  is listed under Average Fit (AVEFIT).

## 5. RESULTS AND DISCUSSION

The test data are summarized in Tables 1 and 2. The first column lists PF ranges. The second column is the number of test trials falling within each PF range. The second column is the number of test trials falling within each calculated PF range. The third column presents the cumulative-percentage of test trials that resulted in a PF below the upper limit of the range and the fourth column presents the percentage of trials that exceed the lower limit of the range shown.

Table 1. Protection Factor Results from Part A Exercises

PF	Frequency	Cumulative %	Pass %
0	0	0.00	100.00
0-10	0	0.00	100.00
10-20	0	0.00	100.00
20-50	0	0.00	100.00
50-100	0	0.00	100.00
100-500	1	3.33	96.67
500-1000	3	13.33	86.67
1000-1667	2	20.00	80.00
1667-2000	2	26.67	73.33
2000-6667	21	96.67	3.33
6667-10000	1	100.00	0.00

Table 2. Protection Factor Results from Part B Exercises

PF	Frequency	Cumulative %	Pass %
0	0	0.00	100.00
0-10	0	0.00	100.00
10-20	0	0.00	100.00
20-50	0	0.00	100.00
50-100	0	0.00	100.00
100-500	2	7.69	92.31
500-1000	8	38.46	61.54
1000-1667	1	42.31	57.69
1667-2000	1	46.15	53.85
2000-6667	11	88.46	11.54
6667-10000	3	100.00	0.00

The suit achieved 100% passing at a PF of 100 for both parts A and B. The results from Part A are slightly better than Part B because it is a shorter amount of exercises, while Part B is much longer and the subjects have a larger chance of breaking a seal. The results from the "Roll walls and ceiling" exercise are much lower than the average fit value. This exercise in particular is one, which creates a leak in this particular suit. One may notice that the



total frequencies do not add up to 32 total trials. This is because some data had to be removed due to human error. Data skewed by human error does not accurately portray the performance of the suit. This data is not included in Appendix B.

## 6. CONCLUSION

The SE -SHIELD Suit with the SE 400 PAPR performed very well as compared to historical data of other commercially available negative pressure Level B suits. Historical testing of OSHA Level B suits have given results of a PF of 2 through 10, protecting the wearer from liquid CW agents but only providing minimum protection from a vapor or aerosol threat. By pressurizing the SE SHILED suit, PF values have increased, protecting the wearer from liquid CW agents as well as providing protection from a vapor or aerosol threat. Reports detailing findings of other Level B suit performance can be found at the Homeland Defense website: <http://hld.sbccom.army.mil/ip/reports.htm#suits>.

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APPENDIX A

ANTHROPOMETRIC DATA

Subject	Face		Height (in.)	Waist (in.)	Chest (in.)	Inseam (in.)
	Length (mm)	Width (mm)				
1	123	147	71	39	42	30
2	130	149	72	37	40	32
3	131	137	70	33	35	31
4	131	140	70	29	36	32
5	122	134	67	28	34	30
6	124	127	71	31	35	30
7	126	141	69	32	38	30
8	130	144	71	39	43	32
9	128	126	67	31	35	32
10	122	130	70	30	34.5	32
11	118	134	71	31	37	33
12	119	139	68	36	38.5	34
13	130	134	70	38.5	45	32
14	125	136	67	33	36	34
15	129	143	70	38	42.5	32
16	119	140	67	33	38	30

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**APPENDIX B**  
**PROTECTION FACTOR DATA**

Detailed Data from Part A Testing

DATE	TIME	MASK	SUBJECT	Suit Number	TRIAL	ITEM	Exercise (Protection Factor)								
							AVEFIT	1	2	3	4	5	6	7	8
12/7/02	10:40:46	SE-10	1	SUIT 8	1A	PAPR 1	2232	11132	1915	2121	1522	1602	1664	2345	5224
12/7/02	12:00:08	SE-10	1	SUIT 8	2A	PAPR 1	3022	9268	2612	1746	2027	2291	2811	5371	8953
12/7/02	10:40:48	SE-3	2	SUIT 7	1A	PAPR 9	2532	7543	2986	2397	1384	1895	2121	3147	4246
12/7/02	12:00:09	SE-3	2	SUIT 7	2A	PAPR 9	693	10513	140	900	1271	2139	4470	823	1934
12/7/02	10:40:49	SE-1	3	SUIT 6	1A	PAPR 3	1370	8068	2073	1147	558	1049	1869	1646	2105
12/7/02	12:00:10	SE-1	3	SUIT 6	2A	PAPR 3	281	3375	155	554	429	100	227	357	2440
12/7/02	10:40:50	SE-11	4	SUIT 5	1A	PAPR 5	2270	10756	4161	1872	1097	1670	1951	2869	3499
12/7/02	12:00:11	SE-11	4	SUIT 5	2A	PAPR 5	2144	7738	1164	2148	1133	1680	2844	3341	6727
12/7/02	11:22:58	SE-4	5	SUIT 4	1A	PAPR 6	2725	5485	2004	2022	1833	3752	3383	2701	3542
12/7/02	12:42:26	SE-4	5	SUIT 4	2A	PAPR 6	2376	5904	1509	2128	1273	3252	3346	2782	3183
12/7/02	11:23:00	SE-2	6	SUIT 3	1A	PAPR 2	627	4671	150	360	1164	1557	1825	1637	2149
12/7/02	12:42:27	SE-2	6	SUIT 3	2A	PAPR 2	4308	6254	4334	3599	2629	4029	5276	5260	5243
12/7/02	12:42:27	SE-12	7	SUIT 2	2A	PAPR 7	4467	12903	5140	3500	2251	3807	3931	5835	9976
12/7/02	12:42:28	SE-7	8	SUIT 1	2A	PAPR 8	1536	24199	2856	2542	1380	1048	895	714	4459
12/7/02	13:27:35	SE-10	9	SUIT 8	1A	PAPR 1	2633	9876	2129	1872	1503	2057	3558	3513	4634
12/7/02	14:41:15	SE-10	9	SUIT 8	2A	PAPR 1	3827	10488	2265	3306	1653	3528	7358	9512	8198
12/7/02	13:27:35	SE-3	10	SUIT 7	1A	PAPR 9	4173	10943	5153	3002	3169	2052	5012	5970	7763
12/7/02	14:41:16	SE-3	10	SUIT 7	2A	PAPR 9	5616	28865	21129	10002	5171	1205	11754	12410	18720
12/7/02	13:27:37	SE-1	11	SUIT 6	1A	PAPR 3	667	12604	117	1325	1264	2166	1563	1907	5279
12/7/02	14:41:18	SE-1	11	SUIT 6	2A	PAPR 3	3694	19184	3148	4190	1085	5911	5521	6491	7643
12/7/02	13:27:38	SE-11	12	SUIT 5	1A	PAPR 5	3266	20859	2316	2518	1930	3029	3215	4121	5845
12/7/02	14:41:19	SE-11	12	SUIT 5	2A	PAPR 5	3604	20290	5205	3391	1427	2513	4517	5183	5855
12/7/02	14:09:43	SE-4	13	SUIT 4	1A	PAPR 6	1928	28000	898	1391	689	2405	5764	8002	8613
12/7/02	15:23:40	SE-4	13	SUIT 4	2A	PAPR 6	8060	9744	9876	7328	6581	5790	9119	10811	7972
12/7/02	14:09:44	SE-2	14	SUIT 3	1A	PAPR 2	2339	5453	2241	2274	1179	1927	3257	2804	3116
12/7/02	15:23:41	SE-2	14	SUIT 3	2A	PAPR 2	5499	8316	6270	5257	4326	5125	5628	5331	5177
12/7/02	14:09:45	SE-12	15	SUIT 2	1A	PAPR 7	1758	75930	926	2095	627	1869	3259	2786	5413
12/7/02	15:23:43	SE-12	15	SUIT 2	2A	PAPR 7	6365	91287	6276	5075	2414	5341	8278	9139	17295
12/7/02	14:09:46	SE-7	16	SUIT 1	1A	PAPR 8	3376	24471	2818	3432	1733	2851	2777	4819	5342
12/7/02	15:23:44	SE-7	16	SUIT 1	2A	PAPR 8	5253	15154	9354	4786	2965	4135	4556	5671	6020

# Detailed Data from Part B Testing

DATE	TIME	MASK	SUBJECT	CONCEPT	TRIAL	ITEM	AVEFIT	Exercise (Protection Factor)*							
								1	2	3	4	5	6	7	8
12/7/02	11:18:08	SE-10	1	SUIT 8	1B	PAPR 1	5235	4082	4586	3003	4172	5186	11573	5609	5705
12/7/02	11:18:09	SE-3	2	SUIT 7	1B	PAPR 9	820	2248	2868	2867	2961	3876	4834	2957	4234
12/7/02	12:37:18	SE-3	2	SUIT 7	2B	PAPR 9	239	134	1691	4600	3474	917	21147	40	1379
12/7/02	11:18:10	SE-1	3	SUIT 6	1B	PAPR 3	817	1096	1427	1432	886	1965	3529	1588	1162
12/7/02	11:18:11	SE-11	4	SUIT 5	1B	PAPR 5	2243	2725	2661	2560	4569	5788	6623	2529	5476
12/7/02	12:37:20	SE-11	4	SUIT 5	2B	PAPR 5	1560	1646	2850	2953	3124	5237	3646	437	5075
12/7/02	12:00:37	SE-4	5	SUIT 4	1B	PAPR 6	2408	2257	2405	2256	2754	4914	7210	1962	3815
12/7/02	12:00:38	SE-2	6	SUIT 3	1B	PAPR 2	2405	1922	2191	2395	2568	2802	4569	521	2387
12/7/02	13:19:37	SE-2	6	SUIT 3	2B	PAPR 2	4779	4957	5322	7290	7860	8254	5265	4461	5859
12/7/02	13:19:38	SE-12	7	SUIT 2	2B	PAPR 7	2259	3591	4042	8954	8380	10130	26691	390	12573
12/7/02	13:19:39	SE-7	8	SUIT 1	2B	PAPR 8	2223	879	3370	3562	4421	11432	40623	540	3608
12/7/02	14:04:29	SE-10	9	SUIT 8	1B	PAPR 1	7888	4651	3522	5095	6786	16020	29088	7438	5849
12/7/02	15:18:42	SE-10	9	SUIT 8	2B	PAPR 1	6757	2037	4552	5741	9637	13502	25159	3928	9191
12/7/02	14:04:30	SE-3	10	SUIT 7	1B	PAPR 9	3766	3301	5554	5464	6401	11797	33524	5547	11636
12/7/02	15:18:43	SE-3	10	SUIT 7	2B	PAPR 9	5073	1958	10923	11618	11399	18366	66166	8522	24208
12/7/02	14:04:32	SE-1	11	SUIT 6	1B	PAPR 3	987	1091	2765	6668	8773	6238	1189	84	6438
12/7/02	15:18:44	SE-1	11	SUIT 6	2B	PAPR 3	616	729	6348	5598	3357	11498	2795	124	6792
12/7/02	14:04:33	SE-11	12	SUIT 5	1B	PAPR 5	769	3737	3644	3612	4461	5914	11980	102	2409
12/7/02	15:18:46	SE-11	12	SUIT 5	2B	PAPR 5	376	598	2965	2631	4539	9633	46142	27	1081
12/7/02	14:46:32	SE-4	13	SUIT 4	1B	PAPR 6	4928	2475	3396	1241	2411	12692	41804	10640	8650
12/7/02	16:00:43	SE-4	13	SUIT 4	2B	PAPR 6	8229	4401	7994	7359	10133	17003	27705	5974	6989
12/7/02	14:46:34	SE-2	14	SUIT 3	1B	PAPR 2	707	2491	3526	3001	2845	5520	8026	113	2414
12/7/02	14:46:35	SE-12	15	SUIT 2	1B	PAPR 7	3113	5886	7246	3106	3860	14467	16823	8374	10627
12/7/02	16:00:45	SE-12	15	SUIT 2	2B	PAPR 7	943	10179	8580	5908	8129	23889	82783	72	5158
12/7/02	14:46:36	SE-7	16	SUIT 1	1B	PAPR 8	1924	442	3096	2655	3345	6074	9956	403	3738
12/7/02	16:00:46	SE-7	16	SUIT 1	2B	PAPR 8	810	8001	6740	5690	4851	9486	28575	945	8120

\*During the four-minute exercises, there was a value calculated every two minutes. That is why there are two values for each exercise.

# Detailed Data from Part B Testing (Continued)

SUBJECT	Exercise (Protection Factor)*							
	5	5	6	6	7	7	8	8
1	4082	4586	3003	4172	5186	11573	5609	5705
2	2248	2868	2867	2961	3876	4834	2957	4234
2	134	1691	4600	3474	917	21147	40	1379
3	1096	1427	1432	886	1965	3529	1588	1162
4	2725	2661	2560	4569	5788	6623	2529	5476
4	1646	2850	2953	3124	5237	3646	437	5075
5	2257	2405	2256	2754	4914	7210	1962	3815
6	1922	2191	2395	2568	2802	4569	521	2387
6	4957	5322	7290	7860	8254	5265	4461	5859
7	3591	4042	8954	8380	10130	26691	390	12573
8	879	3370	3562	4421	11432	40623	540	3608
9	4651	3522	5095	6786	16020	29088	7438	5849
9	2037	4552	5741	9637	13502	25159	3928	9191
10	3301	5554	5464	6401	11797	33524	5547	11636
10	1958	10923	11618	11399	18366	66166	8522	24208
11	1091	2765	6668	8773	6238	1189	84	6438
11	729	6348	5598	3357	11498	2795	124	6792
12	3737	3644	3612	4461	5914	11980	102	2409
12	598	2965	2631	4539	9633	46142	27	1081
13	2475	3396	1241	2411	12692	41804	10640	8650
13	4401	7994	7359	10133	17003	27705	5974	6989
14	2491	3526	3001	2845	5520	8026	113	2414
15	5886	7246	3106	3860	14467	16823	8374	10627
15	10179	8580	5908	8129	23889	82783	72	5158
16	442	3096	2655	3345	6074	9956	403	3738
16	8001	6740	5690	4851	9486	28575	945	8120

\*During the four-minute exercises, there was a value calculated every two minutes. That is why there are two values for each exercise.